SLEEP-BASED MEMORY CONSOLIDATION AND AGING

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Introduction

Sleep is an often-overlooked aspect of life, even though sufficient quality and quantity of sleep is imperative for the maintenance of physiological homeostasis, the body's state of dynamic consistency. Specifically, this resting state allows humans and other animals to wash out toxins, regulate the body's metabolic rate, and stabilize hormone concentrations, to name a few (Ezenwanne, 2011). Despite this, younger adults in the college setting are under the impression that sacrificing hours of sleep can allow them to be more productive and as a result often "pull all-nighters," in which students continue to study throughout a sleepless night. In some settings, the drive to earn higher grades or finish time-consuming projects may even prove to be a characteristic of toxic millennial culture as younger individuals engage in competitive sleep deprivation behavior among friends and colleagues. Regarding the other end of the age spectrum, the National Sleep Foundation (NSF) reveals that older adults commonly report having trouble falling and staying asleep compared to their younger selves. This is evident when we look at objective NSF data revealing that while individuals from 18-54 years of age sleep an average of 7.6 hours on weekends, those between 55-84 years of age receive 7.1 hours of sleep in comparison. This suggests that though sleep disruption can occur in all ages, chronic sleep deprivation becomes more prevalent with age.

There is substantial evidence that aging is accompanied by deterioration in memory function, changes in brain structure, and sleep dysfunction (Nyberg, Lövdén, Riklund, Lindenberger, and Backman, 2012). Between working- and long-term memory, the relationship between aging and memory reveals a larger decline in long-term, specifically episodic memory, although working-term memory is also greatly reduced. With regard to structural differences in the brain, aging promotes the shrinkage of gray matter volume due to neuronal cell death, leading to altered synaptic plasticity in which the synaptic connections between neurons weaken over time (Peters, 2006). Older adults also self-report being less satisfied with sleep and feeling tired during the day, which aligns with data that reveals high sleep latency—the length of time it takes to fall asleep—and sleep fragmentation—the number of awakenings that occur during a sleep period—are associated with an overall decrease in time spent in rapid eye movement (REM) sleep (Gui et al, 2007).

Literature Review

Partial sleep deprivation, characterized by less than 5 hours of sleep in a 24-hour period, has been found to have a greater effect on daily functioning than long-term (>45 hours) and short-term (≤45 hours) sleep deprivation as it relates to mood, motor, and cognitive performance (Pilcher *et al,* 1996). This suggests that losing even a few hours of sleep for one night's rest can have substantial changes on emotional, physical, and mental health. Long-term sleep deprivation, however, can lead to changes in the brain's functional activity. In one study, seventy-two hours of continuous wakefulness was correlated with glucose hypometabolism in a number of brain structures, including the prefrontal cortex. These results imply that being awake for too long can havoc dangerous effects on the region of the brain most important for planning complex cognitive behaviors, personality expression, decision making, and social behaviors (Orzel-Gryglewska, 2010). In terms of mental functioning, subjects showed aggression, deteriorated interpersonal relations, and affective symptoms of psychopathology, including anxiety, depression, and paranoia following 56 hours of continuous wakefulness (Kahn-Greene, Kilgore, Kamimori, Balkin, and Killgore, 2007). Understanding how the lack of sleep impacts architecture within the brain therefore allows researchers to ultimately understand human behavior.

In exploration of the effects of sleep disruptions on specific age groups, Sariarslan and colleagues (2015) observed that older participants had poorer sleep quality than younger participants. These results can be attributed to common sleep problems, such as sleep apnea, snoring, daytime sleepiness, restless leg syndrome, or insufficient sleep in the older adult age population. It makes sense, then, that older adults often complain about earlier wake times, lighter sleep, increased wakefulness, and decreased total time asleep (Crowley, 2011). Just as insufficient sleep is reported with advancing age, it is interesting to also consider a specific aspect of the young adult population. The college student sample also provides well-documented sleep difficulties due to a transition period enabling students to develop independent schedules and sleep behaviors. For example, one study reported that like older adults, young adults with limited social rhythms and inconsistent daily activities have poor sleep quality (Carney, Edinger, Meyer, Lindman, and Istre, 2006).

Several other studies have found that young adults are more vulnerable to the effects of sleep deprivation when compared to older adults. Smulders and others (1997) studied the effects of sleep loss on task performance on both young and elderly subjects, in which electroencephalography (EEG) results indicated higher cortical arousal levels for the elderly than for the young. These results were consistent with the inverse-U relationship between arousal and performance, suggesting that young adults are more sensitive to the detrimental effects of sleep loss than older adults are (Smulders, Kenemans, Jonkman, and Kok, 1997). Using data from the behavioral risk factor surveillance system (BRFSS), another study also showed that the highest and lowest levels of insufficient sleep were reported in young adults and older adults, respectively (Grandner *et al.,* 2015).

Aging, like many other variables, is associated with a decrease in cognitive functioning. The most salient of these age-related declines include episodic memory (Nyberg, Lövdén, Riklund, Lindenberger, and Backman, 2012). Recent studies offer a positive outlook on cognitive aging, as not all forms of human memory are equally affected by advancing age (Grady and Craik, 2000). There seem to be only slight changes in implicit, short-term, and recognition memory task performances, whereas age-related losses are substantial in prospective and working memory tasks that require information to be held in the mind while dealing with other external stimuli. This suggests that aging can mediate different effects on performance, depending on the type of memory the task activates (ex: explicit, implicit, autobiographical, etc).

Fortunately, some aspects of memory functioning in old age can be preserved though sleep. One study trained subjects with motor skill tasks and found that the older adults who were afforded a 90-min nap immediately after training displayed robust performance gains in both speed and accuracy. (Korman, Dagan, and Karni, 2015). As such, the study suggests that sleep can moderate some age-related limitations on long-term plasticity. While memory consolidation may be facilitated through a napping paradigm, there is little evidence whether the length of sleep provided in a nap may be just as efficient as nocturnal sleep. Mednick *et al.* (2003) showed that a 90-minute nap showed 50% more improvement on a texture discrimination task than the 24-hour control group, indicating that a 90-minute nap is just as beneficial as a night's rest. On the other hand, nap architecture differs for young and older adults, with young adult naps containing both NREM and REM bouts and older adult naps dominated mostly by lighter NREM stages (Mantua and Spencer, 2017). These incompatible results encourage researchers to more carefully consider napping vs. stable nocturnal sleeping paradigms.

The individual relationships between age and sleep, age and memory, and sleep and memory are well-studied. However, age-related changes to sleep-based memory consolidation remains unclear. Some studies found older adults benefitted as much as younger adults in consolidating episodic memories after sleep, while others suggested procedural memory may be preserved. (Gui *et al.,* 2017) sought to explore the age-related differences on sleep based memory consolidation for specific memory types using a meta-analysis, and found that older adults compared to young adults had impaired sleep-based declarative memory consolidation but relatively preserved procedural memory.

The scarcity of empirical findings in this field makes it worthwhile to scrutinize the age-related changes in sleep on daily cognitive functioning. Changes in sleep architecture in older adults may interrupt the memory consolidation process during sleep, affecting overall memory performance. In another point of view, structural and functional changes in the aging brain may also affect this consolidation process during sleep. It is uncertain what accounts for the weakened sleep-memory link in older adults. Several studies have suggested different physiological and neurochemical explanations for the weakened age-related sleep-based memory consolidation, such as the possibility of affecting memory encoding and consolidation processes due to deterioration in general memory function, structural and functional alterations of the prefrontal cortex and hippocampus over time, and hypofunction of neurotransmitters that can block the transfer of information from the hippocampus to the neocortex. Although multiple mechanisms may explain these observations, it would be beneficial to find a more consistent answer to this phenomenon. On these grounds, the current study focuses provide more support to these already existing explanations.

Apart from exploring the relationship between age, sleep, and memory, a distinct relationship between personality and sleep will also be investigated out of interest. To account for this variable, a Big Five Inventory (BFI), along with the subjective sleep measures, were completed by each participant. The BFI used in this study is a brief, short-phrase 44-item inventory that describes an individual's personality based on five dimensions: extraversion, agreeableness, consciousness, neuroticism, and openness (John & Srivastava, 1999). A few studies have examined the link between sleep and personality. Gray and Watson explored this association between sleep and personality, showing evidence that sleep quantity is not correlated with any of the personality dimensions, although sleep quality is an indicated of long-term functioning. For example, individuals that scored high on the neuroticism subscale generally reported lower sleep quality, measured by the correlations between neuroticism/negative emotionality and subjective sleep inefficiency (0.43-0.48) as well as PSQI (0.38-0.39). On the other hand, extraversion/positive emotionality was negatively correlated with subjective sleep inefficiency (-0.43) and PSQI (-0.29). Using morningness-eveningness questionnaires, it is well-known that evening-type individuals view themselves as more intellectually advanced compared to morning-types (Preckell et al. 2011). Another study investigated how this link modulates cognition, specifically how personality may affect individuals' subjectively assessed intelligence (SAI), and found that narcissism was correlated with more evening chronotypes and higher SAI (Zajenkowski, Jankowski, Stolarski, 2019). The current study seeks to discover further aspects of personality as they relate to subjective and objective sleep measurements as well as memory performance.

Methodology

It is a known phenomenon that older adults tend to get less sleep and lower sleep quality compared to their younger counterparts, getting worse with age. They also often have difficulty falling asleep, which can be described as long sleep latency, and difficulty staying asleep throughout the night, characterized as low sleep quality. The implications of decreased amount of sleep includes impaired memory, inability to concentrate, reduced physical strength, hallucinations, and mood swings, to name a few. Oddly enough, older adults are able to function relatively normally even after fewer hours of sleep. As such, the current study focuses on the interrelationship between age, sleep, and memory to explain how both decreased hours of sleep and lower sleep quality in older adults affect behavior and cognition.

In this study, we conducted a pilot study and recruited 10 younger adults (aged 21-35) and 10 older adults (aged 60-75). A design in Psychopy v3.0 was created to test the participants' memory retention abilities, specifically facial recognition with word pairs. After the memory test, we then used the Wechsler Adult Intelligence Scale (WAIS) as a neuropsychological assessment tool to measure their baseline cognitive skills quantified by full scale IQ, index scores, or subtest level scaled scores. Some of the tests evaluated the participants' verbal comprehension, working memory, perceptual organization, and processing speed by using the Visual Puzzles, Similarities, Digit Span, and Number-Letter Sequencing subtests. The Visual Puzzles subtest contributed to perceptual reasoning skills by allowing participants to figure out which three pieces can be fitted into a given puzzle. The participants were told the pieces may be rotated but cannot overlap one another. The Similarities subtest examined the ability of the participants to think abstractly by finding similarities among words that may not be apparently alike. For example, the words “music” and “ocean” may be similar by undulations. The Digit Span subtest measured short-term auditory memory by requiring individuals to repeat a series of increasing length back to the examiner. The Number-Letter Sequencing subtest required participants to sequence a random order of numbers and letters in alternating numerical alphabetical order. For example, an individual would first connect 1 to A, A to 2, 2 to B, B to 3, 3 to C, and so on. This therefore measures attention and the ability to reorder information in short-term memory. We additionally asked the participants to draw the face of a clock given an empty circle, testing the individual’s spatial perception and possible cognitive impairment.

Objective sleep data was measured by several assessments, including a rendition of the National Sleep Foundation’s Sleep Diary, the Pittsburgh Sleep Quality Index (PSQI), Insomnia Severity Index (ISI), Composite Morningness Questionnaire. The Sleep Diary was to be completed every morning and night over the course of seven days, serving to illuminate insight into the participants’ sleep habits. Several of the patterns recorded included information about potential sleep disturbances, mood immediately after waking up, caffeine intake, and other factors that might affect the individual’s sleep (NSF). The PSQI, like the Sleep Diary, examines sleep habits but in further detail, quantifying sleep duration, disturbances, latency, efficiency, as well as day dysfunction and medication use to determine if the individual has either good or poor sleep quality (Buysse, Reynolds III, Monk, Berman, and Kupfer, 1989). The ISI is a short assessment tool that screens for perceived insomnia and evaluates its severity on a scale from 0 to 28, with a higher number indicating a more severe form of the potential disorder (Bastien, Vallieres, Morin, 2001). The final self-assessment instrument used to measure sleep was the Composite Morningness Questionnaire, which evaluates an individual’s activity level at different times throughout the day and preferred wake/sleep times to indicate a morning-, evening-, or intermediate-type classification (Smith, Reilly, and Midkiff, 1989). In conjunction with these subjective sleep assessments, the BFI was also handed to each participant for completion.

Accelerometers, or sleep tracking devices, were handed to each participant, who wore the accelerometer for 7 days and nights, only taking off the device when showering. In conjunction with accessorizing the accelerometers, participants recorded information in the Sleep Diary as part of their temporary daily routine. Each participant engaged in a second part of the study a week after their initial lab visit, when we received the accelerometer and saved their sleep data into a program called ActiLife. The program allowed us to quantify their sleep in terms of sleep latency, quantity, quality, number of awakenings, and sleep efficiency. The participants then took the same facial/word recognition test, serving as a delayed-retrieval memory post-test.

The methodology described above explains our process during the preliminary study and analysis and focuses mainly on the effect on sleep on cognition and behavior. Once the piloting is completed, we will proceed to look at all the participant data, make adjustments to the study in the case of pitfalls or flawed methodology, and improve the design. The full-scale research project will also implement magnetic resonance imaging (MRI) to examine the structural differences in the brains of younger and older adults. This particular aspect of the protocol was left out during the pilot study to preserve the costs of imaging techniques and to recruit participants that would typically be excluded from participation due to MRI safety hazards. By later supplementing our original design with detailed images of the anatomy and physiology of the brain however, the full-scale study will employ a holistic approach in facets of behavior, cognition, and function.

Results

The current stage of this study is at data collection for the pilot study. We are specifically in the midst of collecting sleep data for 20 younger adults, which we will analyze before recruiting 20 older adults. However, due to special circumstances, data collection has been temporarily halted, and results will be lacking in content as a result. In general, we predict that older adults will display worse sleep in terms of quality and quantity in comparison to young adults. Within the two groups, those that obtained less hours of sleep will potentially experience a decline in cognitive function, quantified by the change in performance from the memory tests after the one-week follow-up. In this way, we are not only studying the effects of age-related sleep loss on memory tasks, but the effects of acute sleep loss on memory consolidation.

Conclusions

Statistical analyses will be run in order to find relationships between specific aspects of sleep, including total time asleep, sleep efficiency, and number of awakenings, and the change in accuracy from the immediate retrieval to the delayed retrieval memory test. It would also be interesting to study how factors affecting sleep, including mood, naps during the day, medication regimens, exercise, caffeine intake, and activity an hour before bed can affect memory performance. Since this information is obtained from the participants' sleep journal, we can make conclusions about how daily activity may determine sleep quality and therefore cognitive performance.

Future Directions and Discussion

As mentioned before, the lack of data while conducting the preliminary study hinders the ability to make definite conclusions about the interrelationship between age, sleep, and memory. We obtained raw data from ten younger adults, and although we need to be cautious when analyzing data due to the limited sample size, we can use the existing data to find potential correlational relationships between variables. Any drawn conclusions may persist when later including the entire dataset due to individual differences. Following data collection from ten older adults, we will make adjustments to our protocol depending on the available younger adult data before recruiting 20 older adults and analyzing the following data set. The future direction of our study involves moving past preliminary analyses into the full-scale research project in which MRI imaging will be utilized to compare functional and structural images of the brain between and within subjects.

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